The authors would like to thank the reviewers for their constructive comments that have improved this manuscript.

The reviewer's comments (or edits) have been numbered using the format Q.L where Q is the reviewer comment and L is the line number referred to in the reviewer uploaded file "reviewer's nhess-2021-241-RC1.pdf". The authors' response to each comment is given below each question/comment using the format R.L.

Q.L9 remove ','

R.L9 The comma has been removed.

Q.L12 I'm sure this will be explained later, but right now I don't understand what this means.

R.L12 The data pairs are shown in Table 2 and the authors have updated the text for clarity. The new text reads: Wet season coinciding water level and precipitation pairs benefit from a dramatic increase in data pairs, improved goodness of fit statistics, and provide a range of physically realistic pairs.

Q.L21 I find this a bit misleading. The fact that such a small SLR causes a doubling of the odds of the 50-year flood event only shows there is a relatively small difference between the 25-year and 50-year event (namely 5 cm), probably be because of relatively modest storm surges. That means Southern California is actually fortunate to not have very extreme high sea levels during extreme events. And that actually makes the area potentially less vulnerable.

R.L21 The authors agree that typical US West Coast storm surge magnitudes are small (~10 cm, Flick et al., 1998) when compared to multi-meter hurricane generated storm surges experienced in regions with wider continental shelfs. Along the US West Coast, tides dominate marine water levels. Urbanized regions have been built to accommodate the spring tides. Ironically, it is this modest storm surge that make the region highly sensitive to even minor changes in sea level. For example, a 10 cm sea level rise results in spring tides being identical to (or larger than) many historical storm event water levels. The impacts of sea level rise on coastal flooding and vulnerability in California have been demonstrated in the literature (e.g., Tebaldi et al., 2012, Vitousek et al., 2017, Taherkhani et al., 2020). Moftkahari et al., (2015) shows the impact of minor sea level perturbations on flooding (Figure 1). San Francisco, in particular, is highly sensitive to even small (3 cm) increases in sea level (red outline, Figure 1).

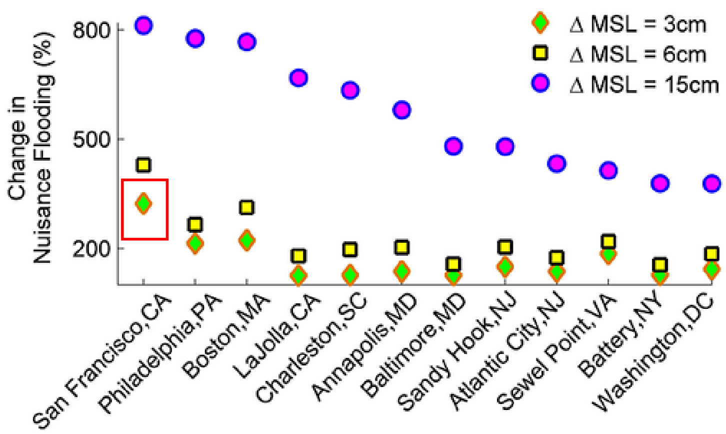

Figure 1. Relative vulnerability along U.S. coast to a unified MSL rise. Adapted from Moftakhari et al., (2015).

Q.L31 I don't understand the second part of this sentence. How can you have different outcomes for an event? An event is single (not plural) so the outcome is single as well. Perhaps you mean different events with the same return period? That would make more sense grammatically. However, in that (multivariate) case it is important to note that the return period loses its meaning (as known in the univariate sense).

R.L31 The authors would like to thank the reviewer for pointing out this inconsistency in the language. The authors have adopted the reviewer's suggestion and updated the text for clarification. The new text reads "Notably, compound events that share a common return period may produce vastly different flooding outcomes.".

Q.L35 remove 'potential'

R.L35 The word 'potential' has been removed.

Q.L36 The more severe of what? Which things are compared here in this univariate case? Or is this the multivariate case in which each variable is analyzed separately? Then please state this more explicitly.

R.L36 The authors have updated the text for clarification. The new text reads "For example, FEMA recommends characterizing compound events by developing univariate water level and discharge statistics, modeling each separately, and then adopting the more severe flooding result for transitional areas (FEMA 2011, 2016c)."

Q.L35 remove "Ironically"

R.L35 The word ironically has been removed.

Q.L81 Reduce?

R.L81 The authors suggestion has been adopted and the text has been updated.

Q.L87 Extended compared to what? I would like to know the period of observations for the three stations.

R.L87 Table 2 in the manuscript shows the observation windows used for the study. The full high/low and hourly OWL and precipitation at all sites up to 8/31/21 are provided for the reviewer in the table immediately below.

	Precipitation		High-Low Tide		Hourly Tide	
Site	Start	End	Start	End	Start	End
Santa Monica	7/1/1948	12/19/2013	8/1/1979	8/31/2021	11/22/1973	8/31/2021
Sunset	7/1/1948	12/1/2012	8/1/1979	8/31/2021	11/28/1923	8/31/2021
San Diego	7/1/1948	12/19/2013	7/1/1979	8/31/2021	8/1/1924	8/31/2021

Using hourly tide data adds over 50 years of additional observed water level records and 31 additional years overlapping precipitation observations for considering compound events at Sunset and San Diego and six years for Santa Monica. The text has been updated to specify the observation windows. The revised text in L84-89 is:

Observed water levels from the Los Angeles (Station ID: 9410660), La Jolla (Station ID: 9410230), and Santa Monica (Station ID: 9410840) tide gauges are available on NOAA's Tides and Currents for daily high-low, hourly, or six-minute intervals (NOAA, 2021 Accessed 2021d). Verified hourly water levels (m

NAVD88) had the longest record length at all three stations and provided an additional 31-years of observations overlapping precipitation data for Los Angeles and La Jolla, and 6-years for Santa Monica. The resulting observations windows are November 22, 1973 to December 19, 2023 for Santa Monica, July 1, 1948 to December 1, 2012 for Sunset and July 1, 1948 to December 19, 2013 for San Diego (Table 2).

Q.L96 Are. How was this done?

R.L96 The authors thank the reviewer for catching this grammatical error. The text has been updated with "are". Precipitation measurements were converted to mm/hr by dividing the total event precipitation by the event time. This is reflected in the revised text which now reads "Precipitation measurements were converted to a mm/hr rate by dividing the total event precipitation by the event time to match the hourly OWL measurements."

Q.L108 remove 'also'

R.L108 The word 'also' has been removed.

Q.L110 replace its with their

R.L110 The sentence has been updated per the reviewer's suggestion and now reads "In the case of coinciding sampling, pairs that had three or more OWL measurements missing within the 24-hour window were manually reviewed and removed if their tidal peak was clearly missing. Specifically, for WMM sampling, months with more than half their observations missing were also reviewed and removed if the tidal peak was missing."

Q.L132 Are

R.L132 The authors thank the reviewer for catching this grammatical error, is has been changed to are.

Q.L150 Kendall scenario.

R.L150 The text has been updated to include the word scenario.

Q.L170 But pdfs are very easy to construct from cdfs with numerical approximations.

R.L170 Uncertainties can be quantified and explored without PDFs, but establishing the most likely events associated to a specific return period requires continuous PDFs . The PDF is generated by taking the derivative of the CDF. Any CDF discontinuities (e.g., in piecewise functions) result in an undefined PDF. Several copulas (e.g., Cuadras-Auge, Shih-Louis, Marshal-Olkin, and Fischer-Hinzmann) employ "min" statements in their CDFs which causes their PDFs (i.e., the derivative of the CDF) to have undefined locations (e.g., Sadegh et al., 2018). Similarly, Raftery, Linear-Spearman, and Cube copulas are piecewise CDF functions with conditional statements, imparting undefined locations in the PDF. In other cases, (e.g., Gaussian, Student-t, and Husler-Reis) distribution functions embedded into the CDF results in a complex partial derivate for the conditional scenarios which are required to establish the most likely event values.

Q.L171 Therefore it was decided to remove …

R.L171 The text has been updated in accordance with the reviewer's suggestion and now reads "therefore it was decided to remove those copulas…"

Q.L172 Equation?

R.L172 The equation reference has been added after "Conditional 3" to reference the associated equation.

Q.L173 That surprises me. This should not happen with well chosen values of dx and dy.

R.L173 The probability space is divided into grid spacings of 0.0005 between 0 and 0.8 and 0.00005 from 0.8 to 1. This high resolution interval is designed to prevent any poor estimations caused by discretization, but in isolated instances negative probabilities occur when a partial derivative is calculated.

Q.L198 Which probability distributions were used to fit the marginals?

R.L198 Section 4.1 and Table 3 specify the selected probability distributions for marginal statistics by each site and sampling method. The reference to Figure 3 in L198 was removed to avoid confusion.

Q.L230 I wouldn't call this 'impacts' as that word has other meanings in flood risk management.

R.L230 The authors thank the reviewer for pointing this out. The text has been revised and now reads "San Diego WMC conditional CDFs display individual copulas effects (Fig. 5)".

Q.L233 Mutually consistent?

R.L233 The text has been updated and now reads "The Roch-Alegre and Fischer-Kock provide very similar results for both precipitation and water level (black and green lines, Fig. 5a, b, e, f)."

Q.L247 I would like some more elaboration on the number of observations ending up at the upper right side of the isolines. Taking the length of the observation period into account that could provide additional evidence in favor of or against some of the copulas.

R.L247 We will address this comment in two parts: the first addressing the observations surpassing the isolines and the second addressing the length of observations affecting copula selection.

Critical multivariate events may occur in different regions depending on the hazard type. For example, in multivariate drought studies where the axes are precipitation and soil moisture the critical area representing meteorological drought conditions (i.e., non-exceedance-non-exceedance extremes) lies below the isoline (i.e., Region I). Any data pair above and to the right of the isoline would, in this case be considered 'safe' or events of no concern.

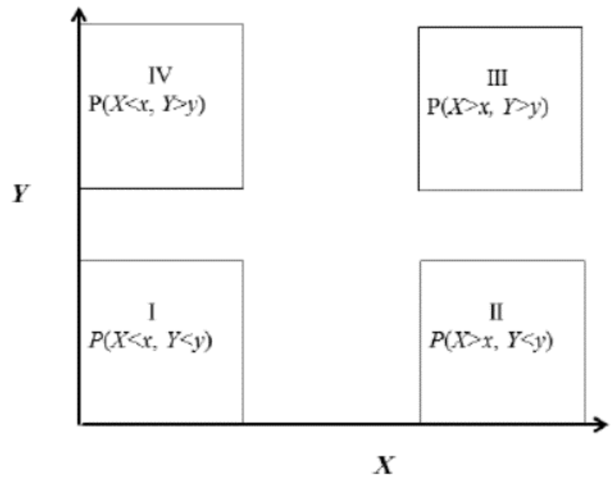

Figure 1, Compound event regions, adapted from Hao et al., (2018).

Conversely, in exceedance-exceedance applications like compound flooding events where, in this study, the axes are precipitation and observed water level the events of interest exist in Region III (Figure 1).

Events above and to the right of the isoline represent more extreme compound events. At the 10 year return period (Figure 2a) a number of exceedance-exceedance events would be expected given the near 70-year observation window. When the return period is more extreme (i.e., 100-year, Figure 2b) pairs on the upper right are minimal or zero for well fit copulas (i.e., Roche-Alegre, Fischer-Kock, Tawn).

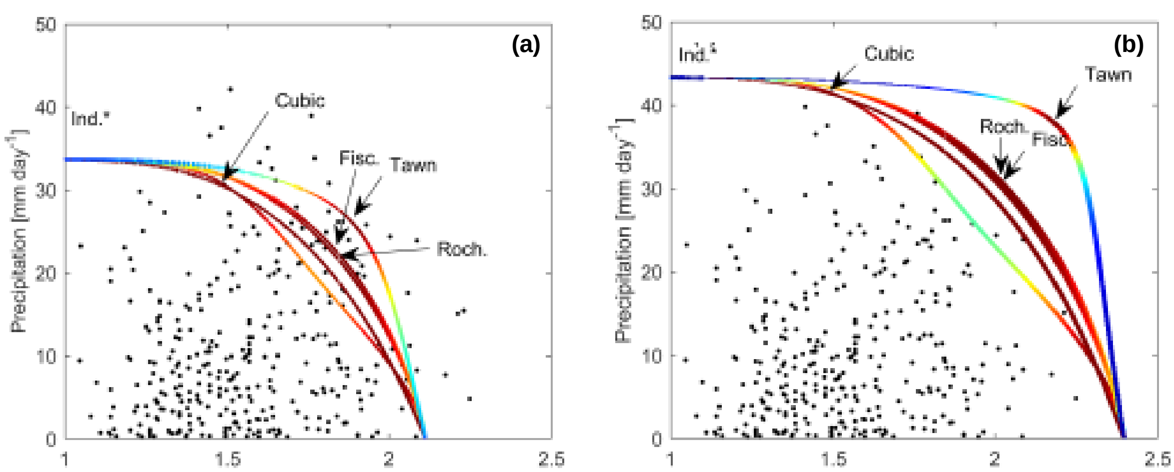

Figure 2 (a) 10 year and (b) 100 year return periods for various copulas using the AND scenario. Adapted from Figures 6a and 7a, Lucey and Gallien, in review.

Alternatively, sampling impacts can be considered in regard to observations above the isoline. Annual Maximum (AM, Figure 3 blue x) sampling pairs the single largest precipitation and OWL observations within a given year (without regard to co-occurrence), which are clearly shown as exceedance-exceedance. Similarly, Wet season monthly maximum (WMM) pairs the single largest precipitation and OWL observations within each wet season month. Maximum parings (annual or wet season) do not represent an observed compound event since the pairs did not co-occur, rather were developed from sampling the largest water level and precipitation event which occurred in a given time frame. This maximum sampling is recommended FEMA guidance as a “worse-case scenario" approach (FEMA, 2016). Unsurprisingly, this manifests as a number of pairs occurring in region III (blue x’s, black dots).

If historically observed, physically realistic events considered using Annual Coinciding (AC) or the Water Month Coinciding (WMC) data pairs, it becomes apparent in the 100-year return period (Figure 3b) that coinciding events are well described by the isoline. Only one event exceeds the isoline (red arrow).

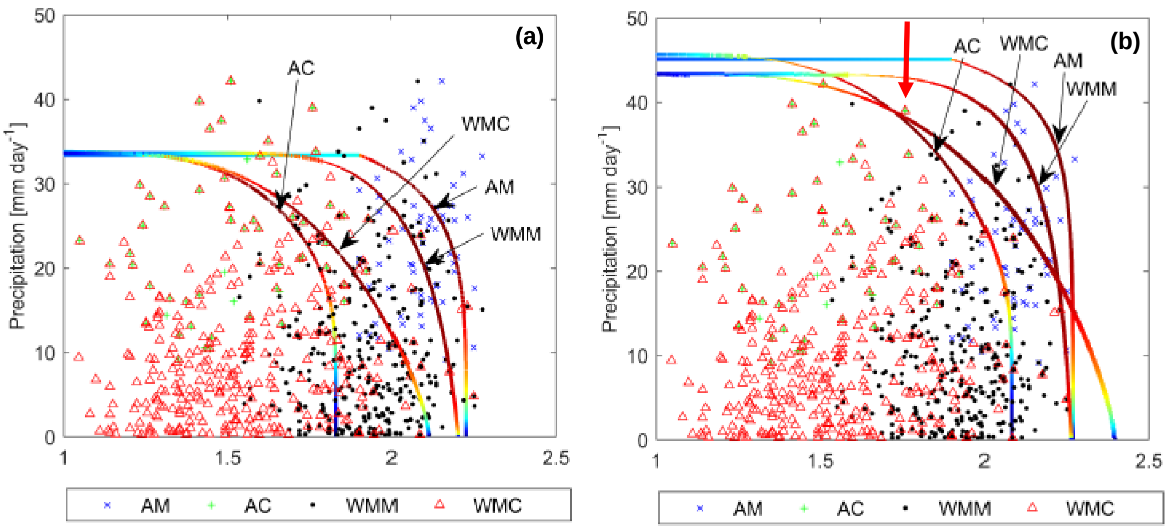

Figure 3, (a) 10 year return period isolines and (b) 100 year return period for the Fischer-Kock.

Second, considering the length of observations (i.e., the number of events) will influence copula selection (Tong et al., 2015, Sadegh et al., 2017).

Tong et al., (2015) explicitly considers data record length on copula selection, distribution characteristics (mean, standard deviation, skewness, autocorrelation), entropy, goodness of fit (Akaike information criterion, AIC), parameter estimator methods, and return period uncertainty. This study utilizes annual maximum flood peak data between 1893 to 2004 along the Yangtze River in China. Only three single parameter copulas are considered: Clayton, Frank, and Gumbel. In circumstances with minimal data availability (<40-years) the best fitting copula varied between the Frank and Gumbel but evolved to a Frank when record lengths were extended (i.e., 40- to 80-years). Copula fittings were insensitive to time period windows (e.g. period between 1910-1992 vs. 1917-1999 were both well fit by the Frank copula). When the data availability was reduced, distribution characteristics varied. For example, entropy, a measurement of disorder (higher entropy meaning a likelier state) decreases with a shorter data length and longer data records improved AIC values (i.e., minimalized the AIC).

In Sadegh et al., (2017), the Tawn (3-parameter), BB1 (2-parameter), and Burr (1-parameter) copulas are fit to precipitation and soil moisture data given 68-years of monthly (816 pairs), 68-years of annual (68 pairs), and 34-years (34 pairs) of annual observations. The Tawn best described the most data dense observations (68 years of monthly data), followed by the BB1 for the 68 years of annual data, and then the Burr for the 34 years of annual data. In this case, the three parameter Tawn was the only copula able to identify an asymmetric dependence between precipitation and (biased towards) soil moisture apparent in the longer, denser data. Additionally, longer records (i.e., increased data availability) reduced uncertainty along the isolines. Although observational record length implications are beyond the scope of this specific study, it is of great interest and we anticipate future work in this area.

Q.L251 One word.

R.L251 The text has been changed to whereas.

Q.L276 remove ‘unique’

R.L276 The word ‘unique’ has been removed

Q.L280 remove ‘also’

R.L280 The word ‘also’ has been removed.

Q.L283 Equal to or greater than.

R.L283 The text has been updated and now reads “A water level equal to or greater than 1.68 m NAVD88 forces valve closures…”

Q.L297 In our study.

R.L297 The text has been revised and now reads “Gaussian and Student t copulas were excluded from this study due to their lack of a computationally simple derivative or integral”

Q.L308 remove ‘likely’

R.L308 ‘likely’ has been removed

Q.L349 – 119, 42

R.L349– All values in the manuscript are provided with two decimal places to maintain consistency.

Q.L364 remove ‘the’

R.L364 ‘the’ has been removed

Q.L366 Particularly

R.L366 The reviewer’s suggestion has been adopted and the revised text reads “…they are fundamental to coastal flooding, particularly in regions…”.

Q.L373 Records are not quadrupled, you just sample more data from the record

R.L373 The authors agree with the reviewer and the text has been revised for accuracy. The new sentence is “Wet season sampling quadruples data pairs (Table 2), providing additional historical joint event information”.

<u>References</u>

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